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(54) **TURBINE ENGINE ROTOR WITH FLEXIBLY COUPLED TIE BOLT**

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F01D 5/06 (2006.01)
F01D 5/02 (2006.01)

(52) **U.S. Cl.**
CPC ***F01D 5/066*** (2013.01); ***F01D 5/026*** (2013.01); *F05D 2240/61* (2013.01); *F05D 2260/38* (2013.01)

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See application file for complete search history.

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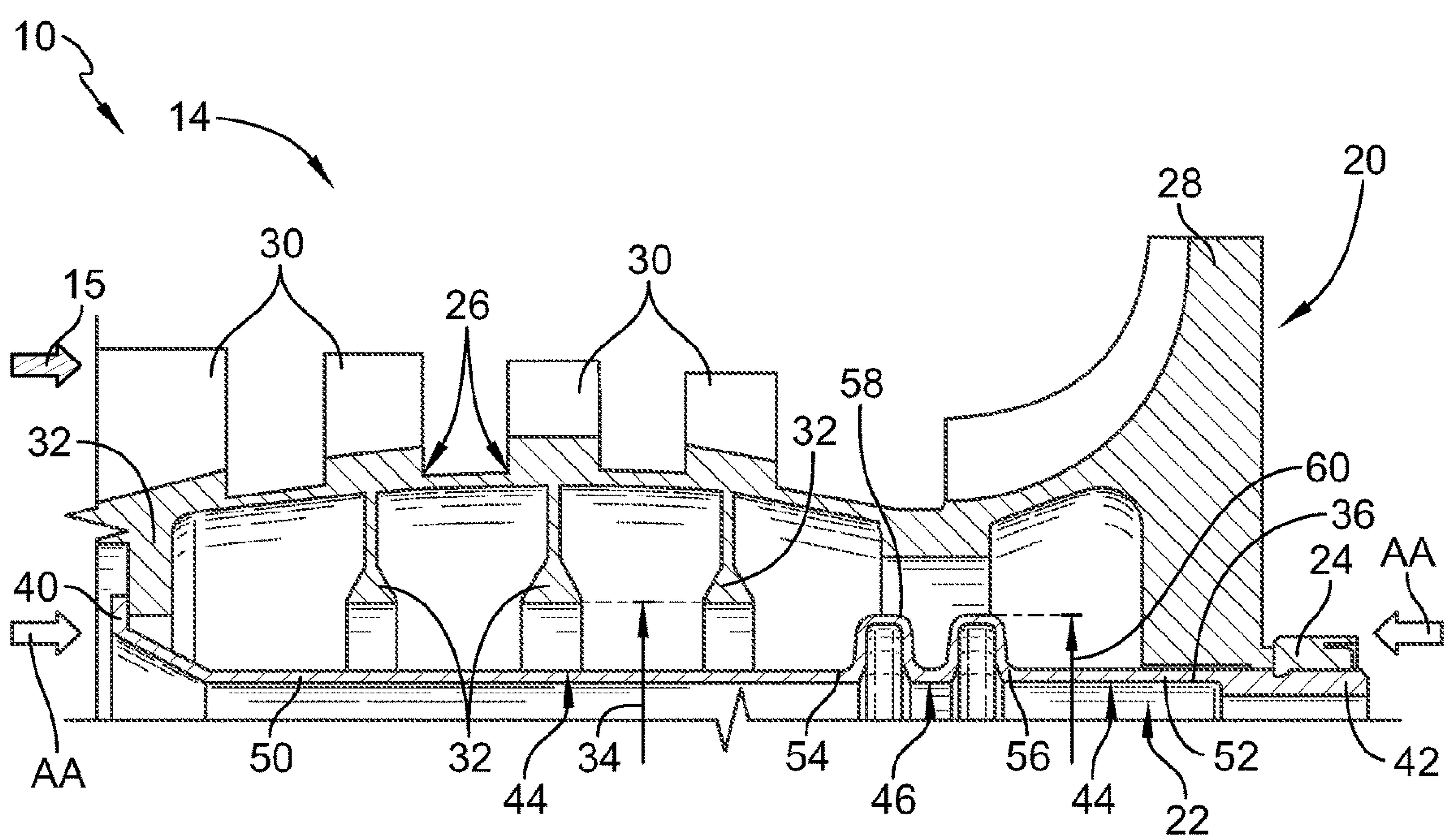
(57) **ABSTRACT**

A rotor assembly includes a plurality of wheels and a tie bolt that extends through the plurality of wheels and applies a compressive force to the plurality of wheels. The tie bolt includes a first segment with a first stiffness and a second segment with a second stiffness to allow for thermal growth of the plurality of wheels.

20 Claims, 5 Drawing Sheets



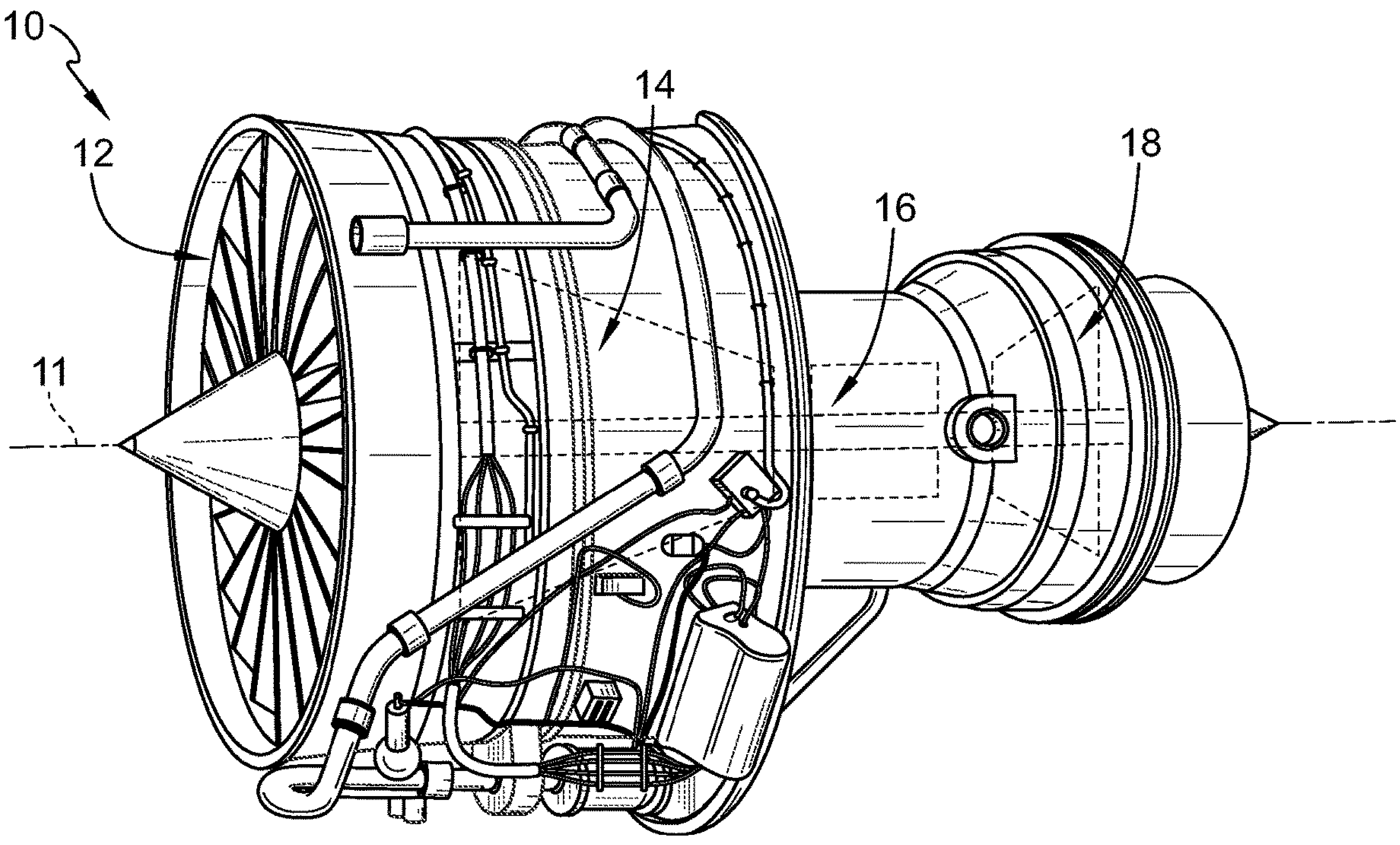

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FIG. 1

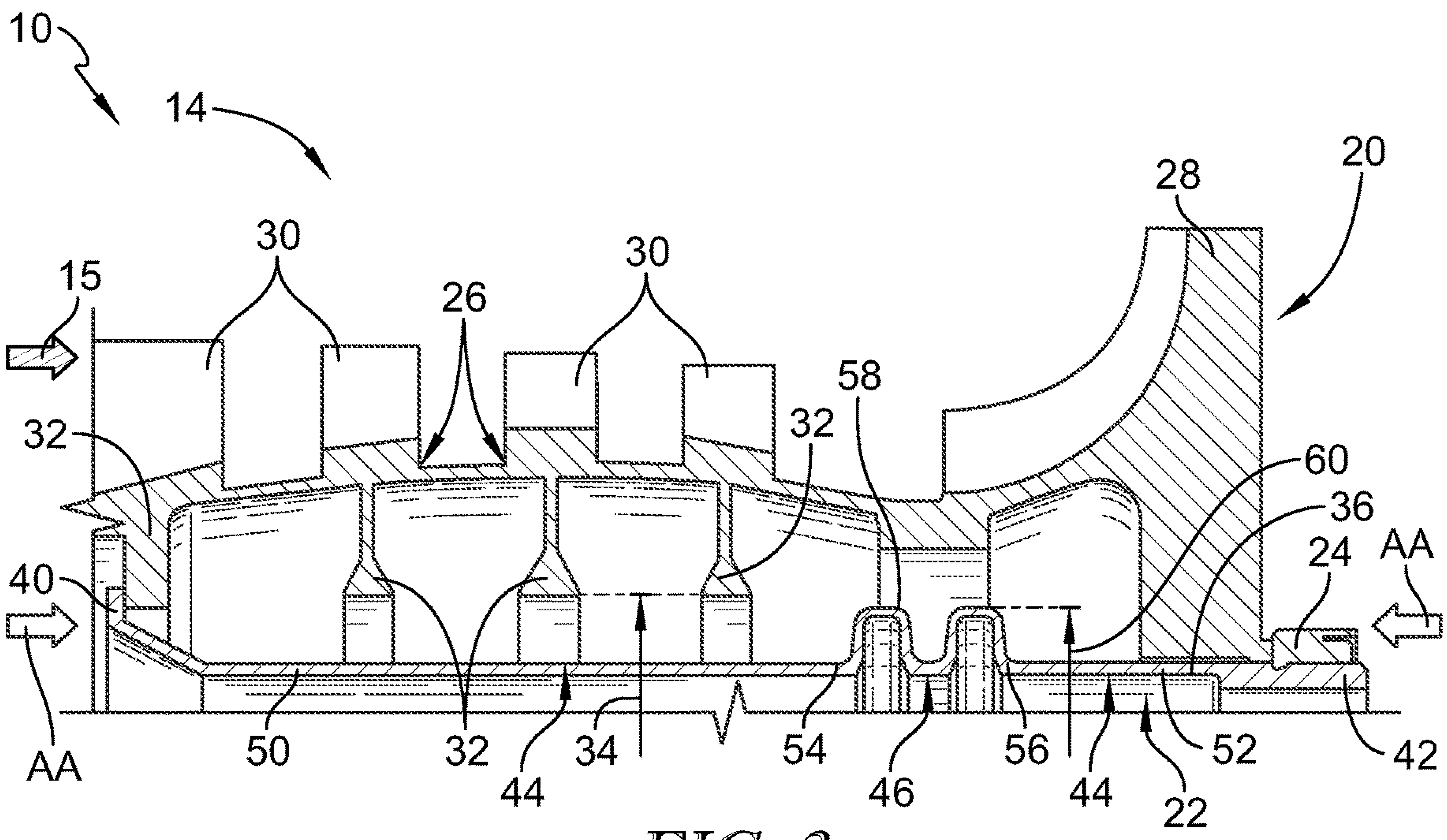
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FIG. 2

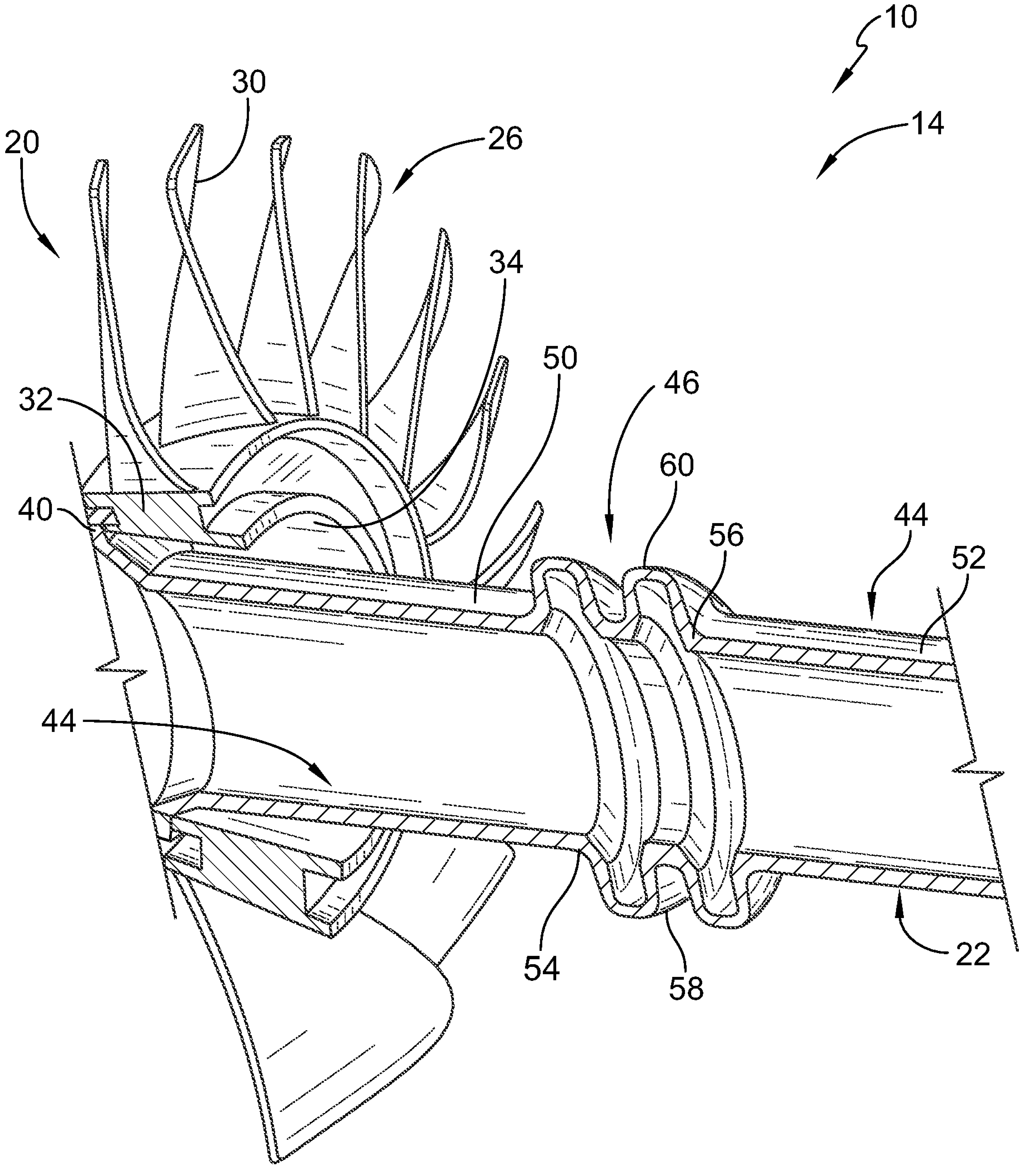

FIG. 3

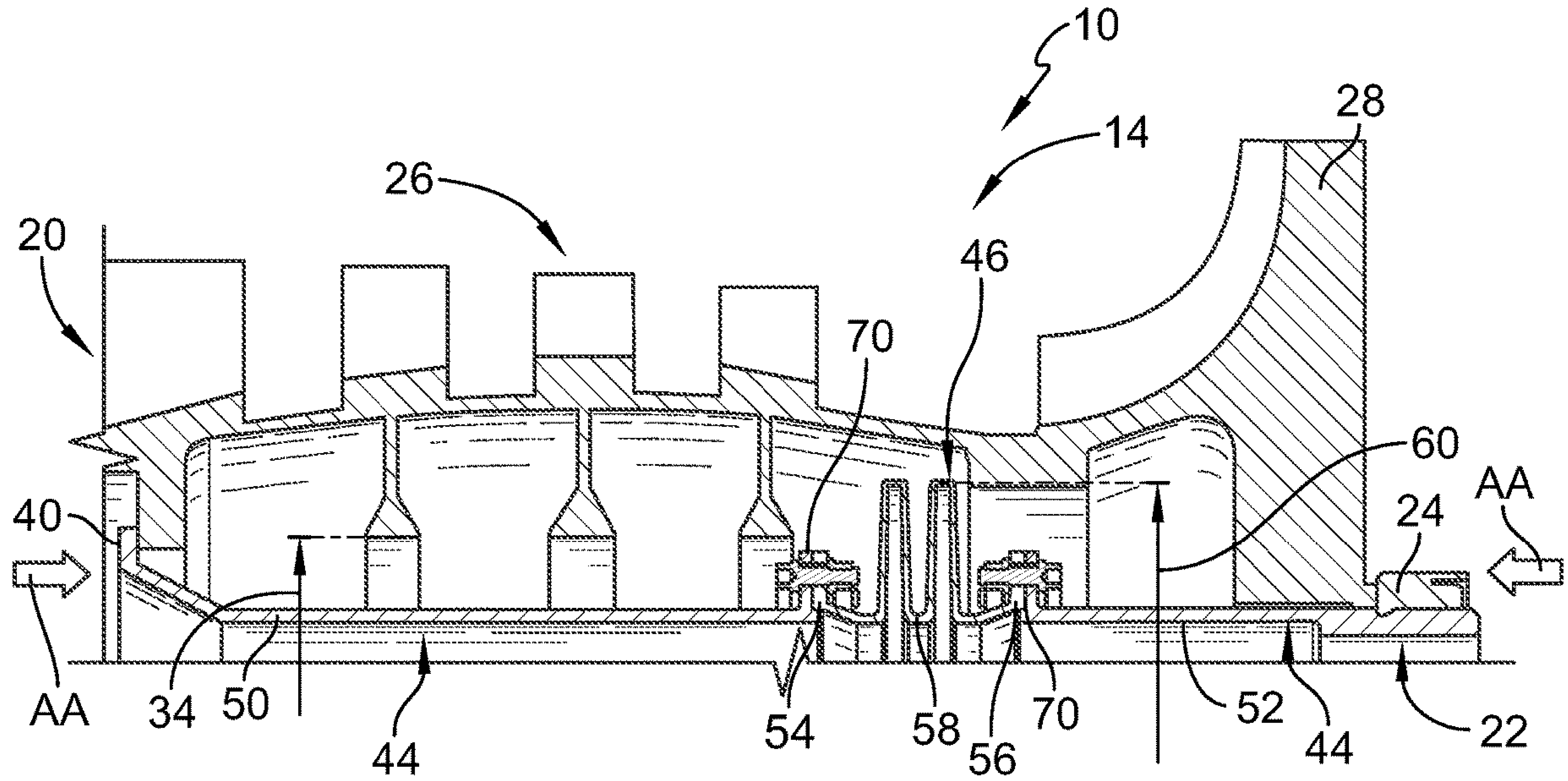
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FIG. 4

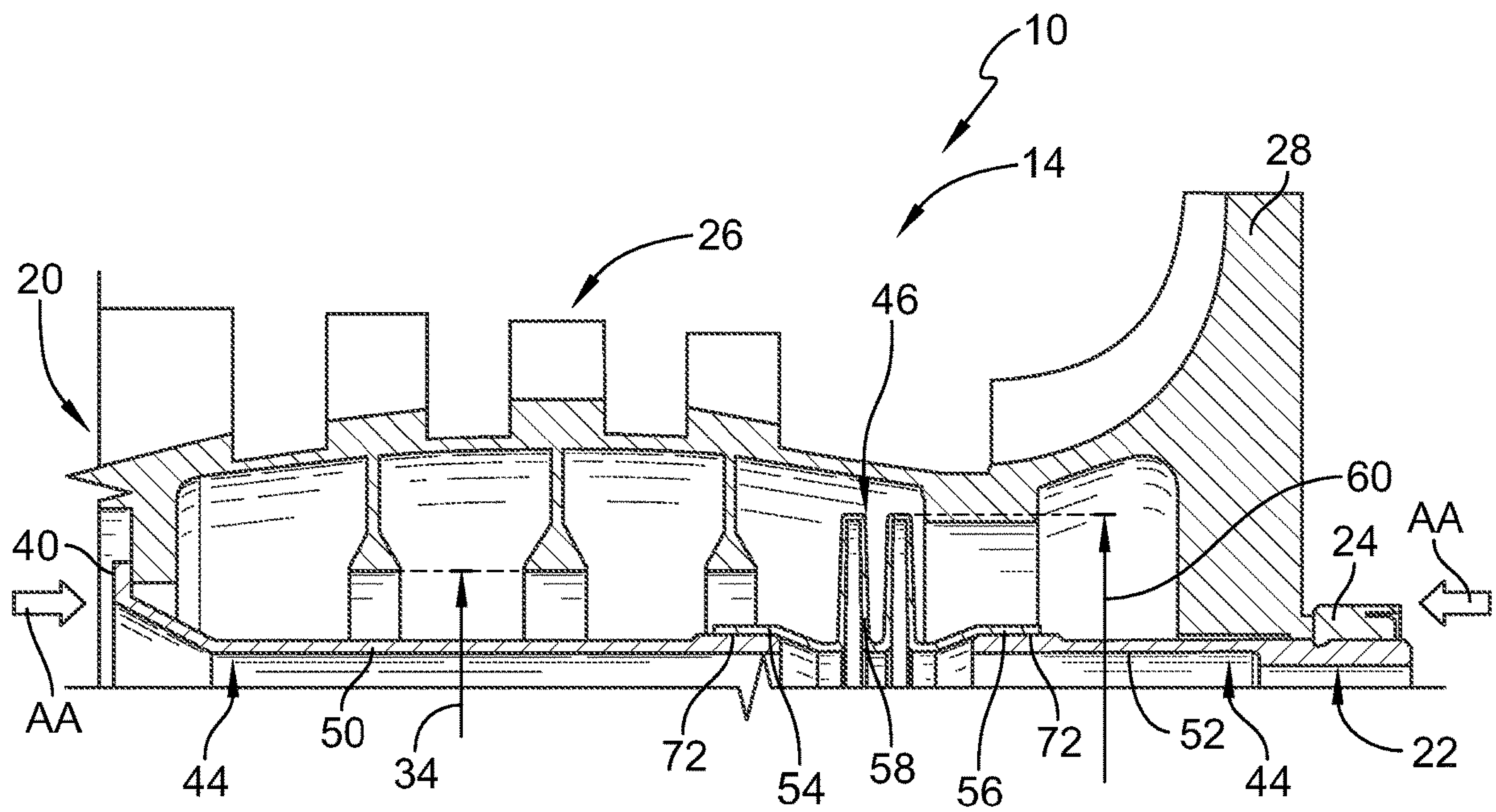
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FIG. 5

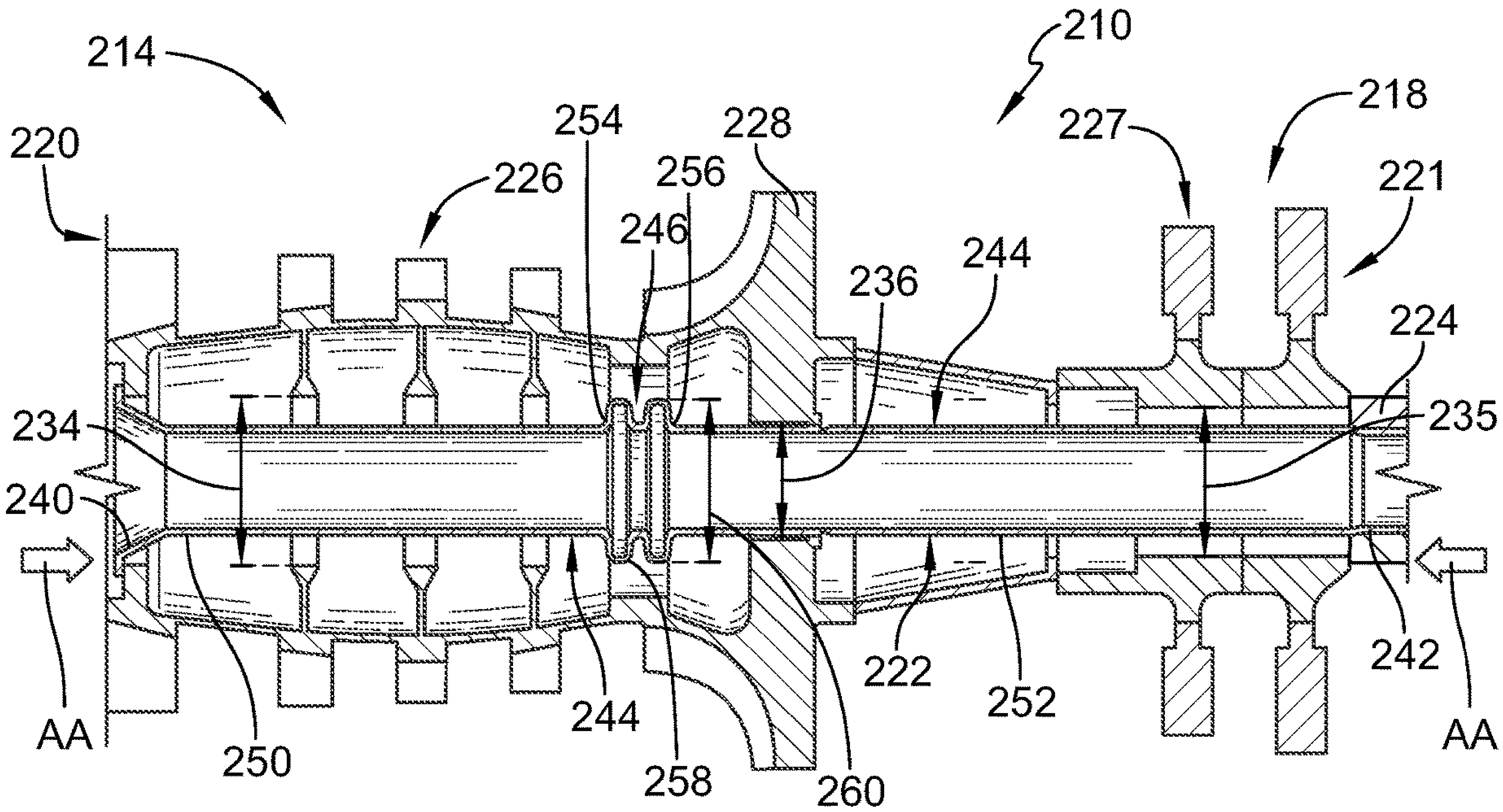
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FIG. 6

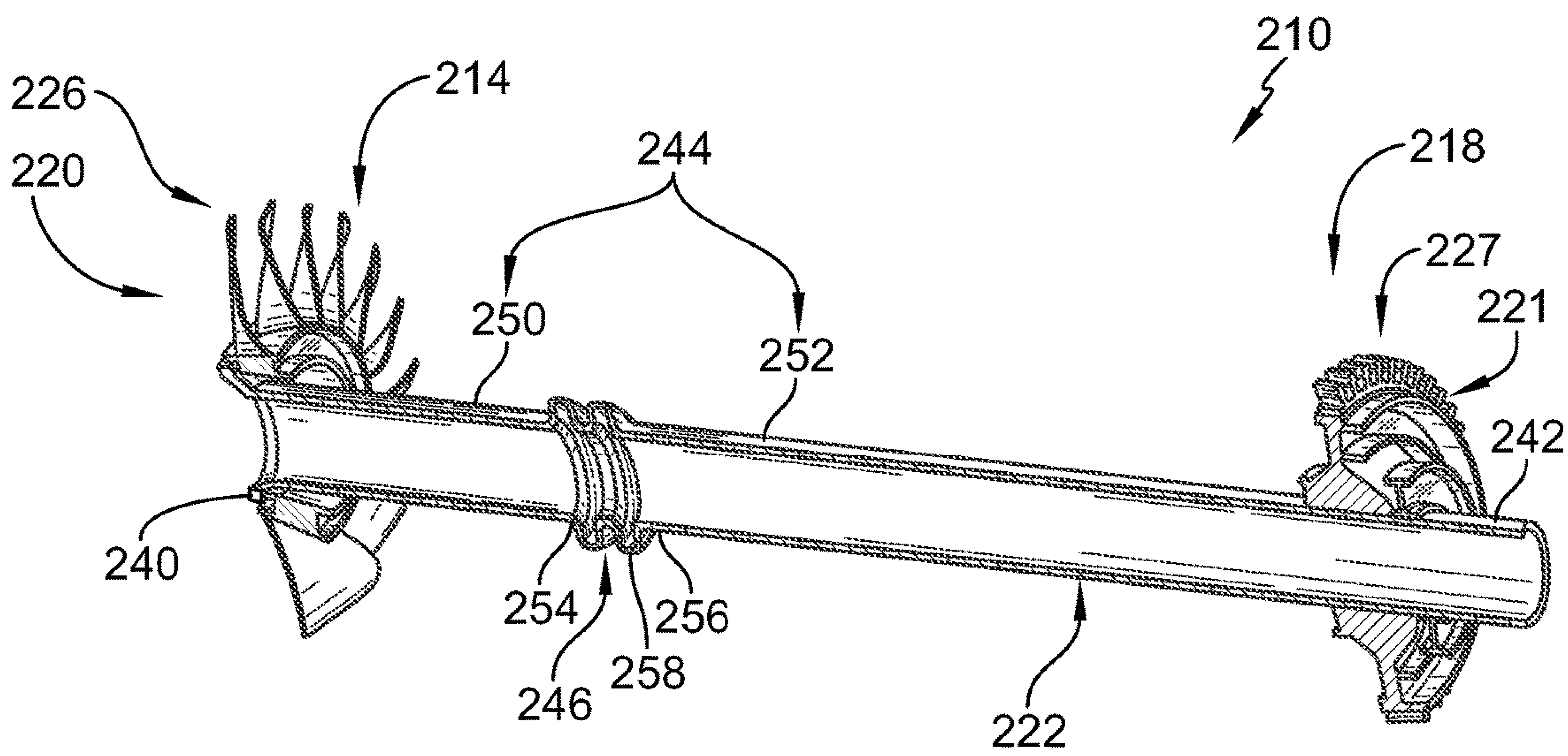
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FIG. 7

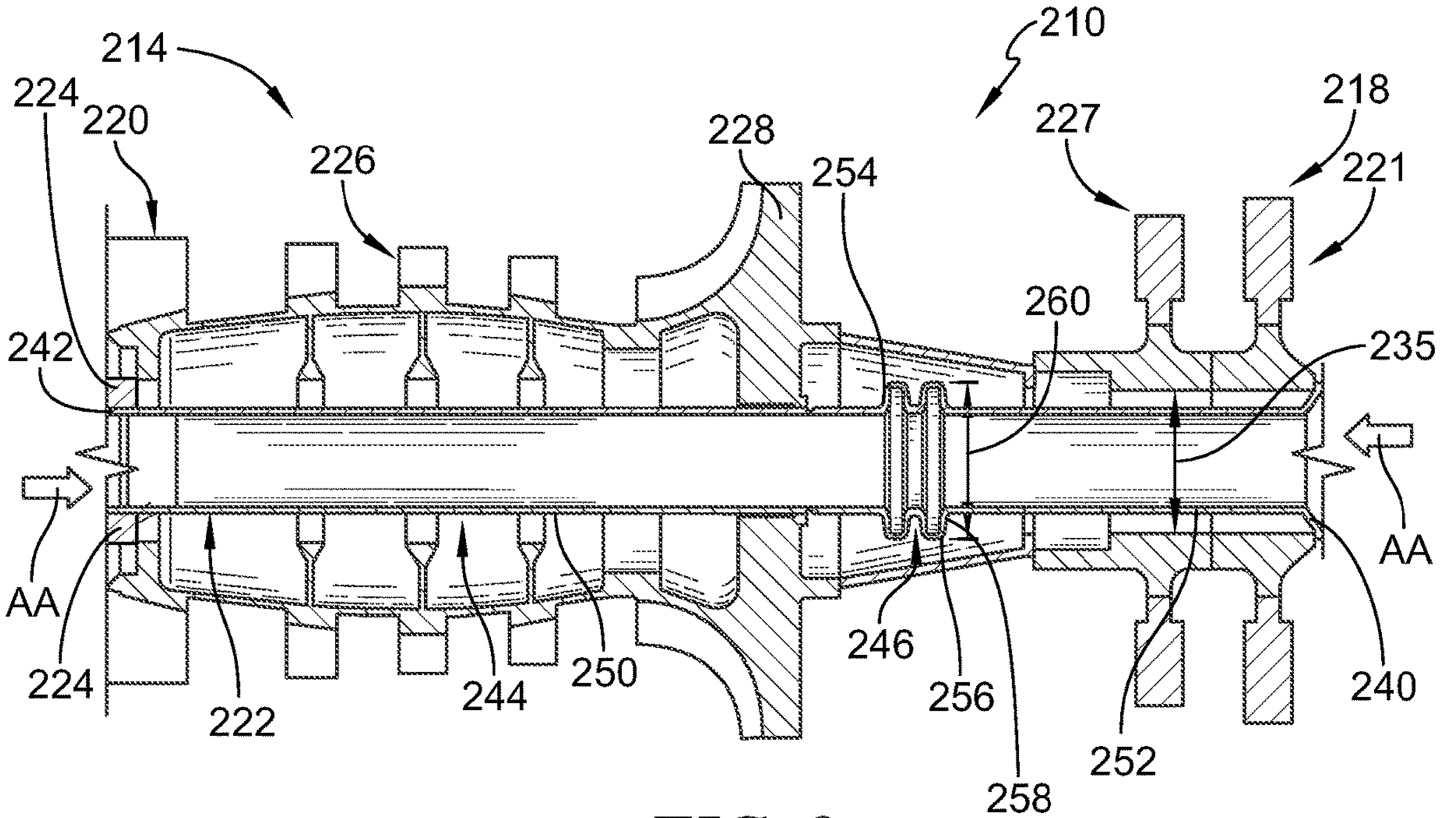

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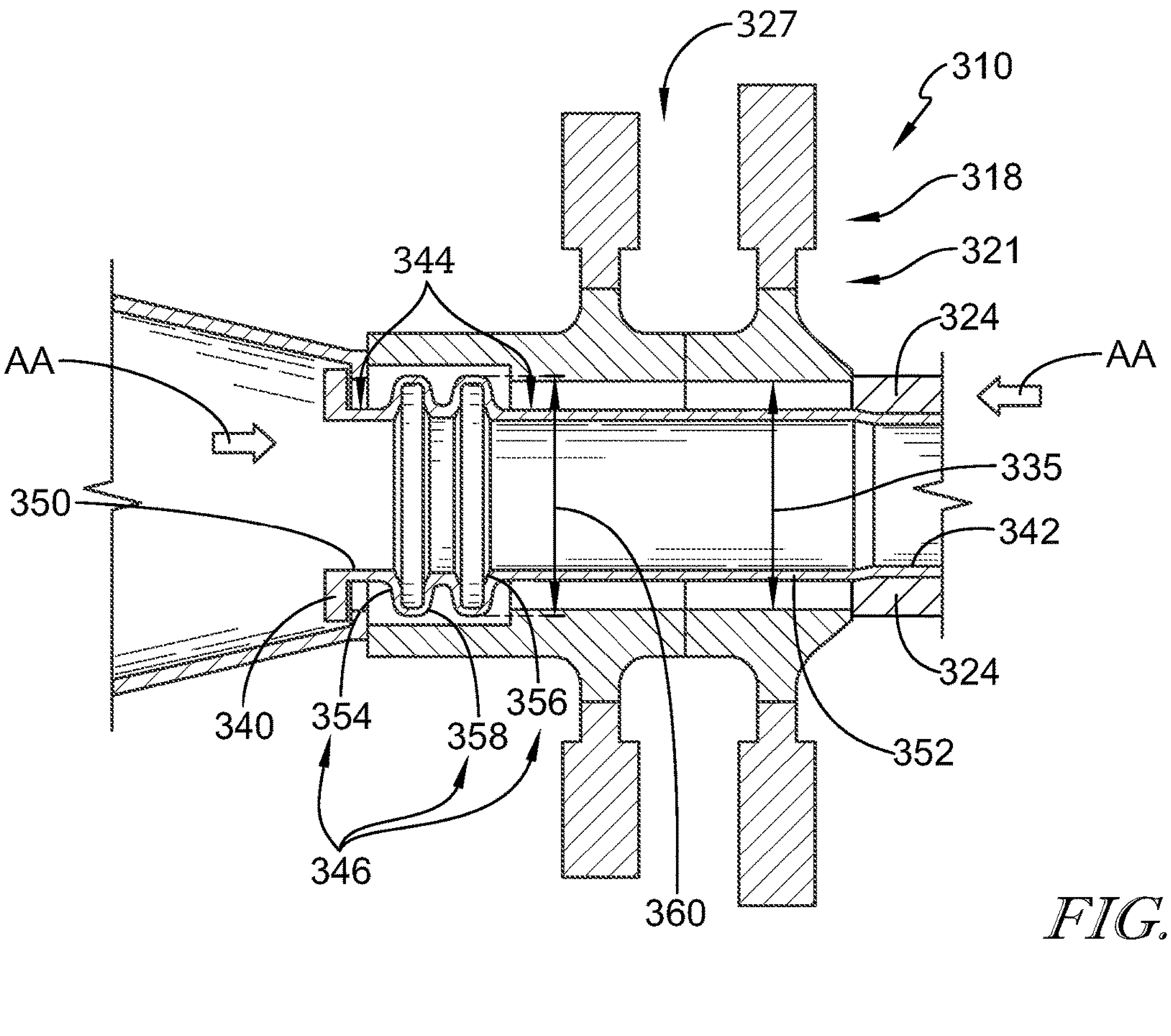
FIG. 8



327
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FIG. 9

TURBINE ENGINE ROTOR WITH FLEXIBLY COUPLED TIE BOLT

FIELD OF THE DISCLOSURE

The present disclosure relates generally to gas turbine engines, and more specifically to rotor assemblies for use in gas turbine engines.

BACKGROUND

Gas turbine engines are used to power aircraft, watercraft, power generators, and the like. Gas turbine engines typically include a compressor, a combustor, and a turbine. The compressor compresses air drawn into the engine and delivers high pressure air to the combustor. In the combustor, fuel is mixed with the high pressure air and is ignited. Products of the combustion reaction in the combustor are directed into the turbine where work is extracted to drive the compressor and, sometimes, an output shaft. Left-over products of the combustion are exhausted out of the turbine and may provide thrust in some applications.

Compressors and turbines typically include alternating stages of static vane assemblies and rotating wheel assemblies. The rotating wheel assemblies include disks carrying blades around their outer edges. The rotating wheel assemblies for a compressor or a turbine are coupled together in series to transfer torque delivered or generated across the multiple rotating wheel assemblies. The multiple rotating wheel assemblies are clamped together by bolted joints, tie-bolt configurations, etc.

Due to the differing coefficients of thermal expansion in a tie-bolt configuration, the rotating wheel assemblies and the tie bolt may expand at different rates through different point of an engine cycle. This may cause the rotating wheel assemblies to shrink faster than the tie-bolt resulting in a loss of clamp load across the wheel-to-wheel joints. High loads may be applied at assembly to pre-stretch the tie-bolt to accommodate for the potential thermal expansion differences of the components.

SUMMARY

The present disclosure may comprise one or more of the following features and combinations thereof.

According to the present disclosure, a gas turbine engine may comprise a rotor and a tie bolt. The rotor may include a plurality of bladed wheels configured to rotate about an axis and interact with gases located radially outward of the rotor. The tie bolt may extend axially through the rotor along the axis and applies an axial compressive force to the plurality of bladed wheels to maintain axial connection between the plurality of bladed wheels. The tie bolt may include a cylindrical segment and a spring segment coupled with the cylindrical segment. The spring segment may have a varying outer diameter to form a bellows feature. The cylindrical segment may have a first stiffness and the spring segment may have a second stiffness that is less than the first stiffness. This may allow the tie bolt to expand and contract with the rotor due to thermal growth caused during use of the gas turbine engine assembly while maintaining the axial compressive force applied to the plurality of bladed wheels above a predetermined value.

In some embodiments, the spring segment may be fastened with the cylindrical segment for rotation therewith. In other embodiment, the spring segment may be threaded to the cylindrical segment for rotation therewith. In further embodiments, the spring segment may be integrally formed with the cylindrical segment. In an additional embodiment, the spring segment may be brazed or welded to the cylindrical segment for rotation therewith.

In further embodiments, the cylindrical segment may be made of first materials. The spring segment may be made of second materials different from the first materials.

In some embodiments, the plurality of bladed wheels includes compressor wheels. In another embodiment, the plurality of bladed wheels further includes turbine wheels.

In other embodiments, the cylindrical segment may include a first portion having a constant outer diameter and a second portion having a constant outer diameter. The spring segment may be located between and coupled to the first portion and the second portion of the cylindrical segment. In further embodiments, the varying outer diameter of the spring segment may have a maximum diameter and at least one of the plurality of bladed wheels has an inner diameter that is greater than the maximum diameter.

According to another aspect of the present disclosure, a gas turbine engine includes a rotor and a tie bolt. The rotor may include a plurality of wheels configured to rotate about an axis. The tie bolt may extend axially through the rotor along the axis and apply an axial compressive force to the plurality of wheels. The tie bolt may include a first segment having a first stiffness and a second segment formed to define a bellows feature and having a second stiffness that is less than the first stiffness.

In some embodiments, the first segment may be coupled with the second segment. The second segment may have a varying outer diameter to form the bellows feature. In a further embodiment, the first segment may include a first portion having a first outer diameter and a second portion having a second outer diameter. The second segment may be located between and coupled to the first portion and the second portion of the first segment. The second segment may have a third outer diameter greater than the first and second outer diameters.

In other embodiments, the second segment may have a maximum diameter. At least one of the plurality of wheels may have an innermost diameter. The innermost diameter of the plurality of wheels may be greater than the maximum diameter of the second segment.

In another embodiment, the plurality of wheels may include an impeller. In a further embodiment, the plurality of wheels includes bladed turbine wheels. In other embodiments, the first segment and the second segment of the tie bolt may be separate components that are coupled together for common rotation about the axis.

According to an aspect of the present disclosure, a method includes a number of steps. The method may include arranging a plurality of bladed wheels around a tie bolt that extends along an axis, the tie bolt including a first segment having a first stiffness and a second segment formed to define a bellows feature and having a second stiffness that is less than the first stiffness, and compressing axially the plurality of bladed wheels with the tie bolt to cause the second segment to deform elastically.

In some embodiments, the method may include coupling the first segment with the second segment for rotation therewith about the axis. In a further embodiment, the plurality of bladed wheels may include a first bladed wheel having a first innermost diameter and a second bladed wheel having a second innermost diameter, the bellows feature having a maximum outer diameter, and the maximum outer diameter is less than the first innermost diameter and greater than the second innermost diameter.

These and other features of the present disclosure will become more apparent from the following description of the illustrative embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a gas turbine engine that includes a fan, a compressor, a combustor, and a turbine, the gas turbine engine including a tie bolt assembly for coupling rotating wheels of the compressor and/or turbine;

FIG. **2** is a cross-sectional view of a portion of the compressor included in the gas turbine engine of FIG. **1** showing the compressor includes a tie bolt and a plurality of bladed wheels, the tie bolt extends through the plurality of bladed wheels to clamp them together, and the tie bolt includes a spring segment that allows for the tie bolt to expand and contract with the plurality of bladed wheels due to thermal growth;

FIG. **3** is a cutaway perspective view of the compressor of FIG. **2** showing with many of the bladed wheels omitted to reveal the tie bolt is located radially inward of the plurality of bladed wheels, the tie bolt includes a cylindrical segment extending forward and aft of the spring segment, and the spring segment includes a bellows feature that extends radially outward and circumferentially around the central axis;

FIG. **4** is the cross-sectional view of a portion of another embodiment of the compressor of FIG. **1** showing the spring segment of the tie bolt is fastened by bolted joints to the cylindrical segments of the tie bolt;

FIG. **5** is the cross-sectional view of a portion of another embodiment of the compressor of FIG. **1** showing the spring segment of the tie bolt is threaded to the cylindrical segments of the tie bolt;

FIG. **6** is a cross-sectional view of a portion of another embodiment of the gas turbine engine of FIG. **1** showing the compressor includes a plurality of bladed wheels, the turbine includes a plurality of turbine wheel assemblies, and the tie bolt extends through the compressor and the turbine and includes a spring segment located forward of an impeller, the tie bolt applying an axial compressive force to clamp the plurality of bladed wheels and the plurality of turbine wheel assemblies together;

FIG. **7** is a cutaway perspective view of the assembly of FIG. **6** with some of the bladed wheels removed to show that the tie bolt includes a forward portion that locates radially inward of the compressor bladed wheels, an aft portion that locates radially inward of the turbine wheel assemblies, and a spring segment located between the forward portion and the aft portion of the tie bolt;

FIG. **8** is a cross-sectional view similar to FIG. **6** showing an embodiment in which the tie bolt includes a spring segment located aft of an impeller, the tie bolt applying an axial compressive force to clamp the plurality of bladed wheels of the compressor and the plurality of turbine wheel assemblies together; and

FIG. **9** is a cross-sectional view of a portion of an embodiment of the turbine included in the gas turbine engine of FIG. **1** showing the turbine includes a tie bolt and a plurality of turbine wheel assemblies, the tie bolt includes a spring segment and extends radially inward and axially through the plurality of turbine wheel assemblies, and the plurality of turbine wheel assemblies are axially clamped together by a compressive force applied by the tie bolt.

DETAILED DESCRIPTION OF THE DRAWINGS

For the purposes of promoting an understanding of the principles of the disclosure, reference will now be made to a number of illustrative embodiments illustrated in the drawings and specific language will be used to describe the same.

An illustrative aerospace gas turbine engine **10** includes a fan **12**, a compressor **14**, a combustor **16**, and a turbine **18** as shown in FIG. **1**. The compressor **14** includes a rotor **20** and a tie bolt **22**. The rotor **20** includes a plurality of bladed wheels **26** that are assembled in series axially and driven by the turbine **18** around a central axis **11** of the gas turbine engine **10**. The tie bolt **22** is located radially inward of the rotor **20** and extends along a central axis **11** and axially clamps the plurality of bladed wheels **26** together.

The tie bolt **22** includes a cylindrical segment **44** and a spring segment **46** as shown in FIG. **2**. The spring segment **46** gives the tie bolt **22** additional flexibility in the axial direction to ease the process of assembling the compressor **14** in the cold-build state while maintaining a compressive force AA on the plurality of bladed wheels **26** through the engine cycle. During the engine cycle of the gas turbine engine **10**, the plurality of bladed wheels **26** and the tie bolt **22** thermally grow at different rates. At some points in the engine cycle the plurality of bladed wheels **26** may cool down faster than the tie bolt **22**, and the axial length of the plurality of bladed wheels **26** becomes shorter than the axial length of the tie bolt **22** compared to the cold-build assembly state of the two components.

In order to maintain the compressive force AA on the plurality of bladed wheels **26** above a predetermined value throughout the engine cycle, the tie bolt **22** is stretched during cold-build assembly to accommodate for the relative thermal growths and the differences in axial lengths during engine running. The compressive force AA may vary during operation of the gas turbine engine **10**. For example, the compressive force AA may be greatest at cold build and during start up and then reduce in magnitude during flight and operation of the gas turbine engine. The tie bolt **22** is configured so that the compressive force AA is maintained at or above the predetermined threshold that keeps the plurality of bladed wheels **26** in a desired compressive state.

A conventional tie bolt does not include a spring section and may use large loads to create the pre-stretch in assembly because of the high stiffness of a conventional cylindrical tie bolt. The spring segment **46** of the present application gives the tie bolt **22** additional axial flexibility to aid assembly, but also allows for the compressive force AA to be applied to the plurality of bladed wheels **26** at all engine cycle points so that the compressive force AA is maintained above the predetermined value even with differing thermal growth of the components. The spring segment **46** may further allow for smaller axially loads to be used on the tie bolt **22** at assembly which may eliminate the use of specialized tools and/or moving the assembly around a shop floor to multiple stations.

The fan **12** is driven by the turbine **18** and provides thrust for propelling an air vehicle. The compressor **14** compresses and delivers air to the combustor **16**. The combustor **16** mixes fuel with the compressed air received from the compressor **14** and ignites the fuel. The hot, high-pressure products of the combustion reaction in the combustor **16** are directed into the turbine **18** to cause the turbine **18** to rotate about a central axis **11** and drive the compressor **14** and the fan **12**. In some embodiments, the fan **12** may be replaced with a propeller, drive shaft, or other suitable configuration.

The compressor **14** includes the rotor **20**, the tie bolt **22**, and a ring nut **24** as shown in in FIG. **2**. The tie bolt **22** is located radially inward of the rotor **20** and extends axially along the central axis **11**. The tie bolt **22** is assembled from a front end of the rotor **20** and extends axially aft through the rotor **20** and past an aft end of the rotor **20**. The ring nut **24** is assembled radially outward of the tie bolt **22** to an aft threaded portion **42** of the tie bolt **22**. The ring nut **24** has a threaded inner diameter that couples with to a threaded outer diameter of the aft threaded portion **42** of the tie bolt **22**. The ring nut **24** has an outer diameter larger than an inner diameter of the aft end of the rotor **20** so that it engages the aft end of the rotor **20** when the ring nut **24** is tightened in the forward direction.

During assembly, the tie bolt **22** is stretched in the axial direction relative to the rotor **20** so that the tie bolt **22** can maintain a compressive force on the rotor **20** through the engine cycle. Once a predetermined value of stretch of the tie bolt **22** has been achieved, the ring nut **24** is tightened against the aft end of the rotor **20** to cause the tie bolt **22** and the ring nut **24** to cooperate and apply the compressive force AA to the rotor **20**.

The rotor **20** includes a plurality of bladed wheels **26** that are assembled in series axially along the central axis **11** as shown in FIG. **2**. In illustrative embodiment, the plurality of bladed wheels **26** includes an impeller **28** at the aft end of the rotor **20**, axially aft of the other of the plurality of bladed wheels **26**. The rotor **20** rotates around the central axis **11** and is driven by the turbine **18**. The plurality of bladed wheels **26** includes multiple stages, each stage including a plurality of airfoils **30** and a plurality of wheels **32** that couple with the plurality of airfoils **30**. In some embodiments, the rotor **20** may include a single stage or multiple stages of bladed disk assemblies. In another embodiment, the rotor **20** may include blisks. In a further embodiment, the rotor **20** may include combinations of bladed disk assemblies, blisks, and impellers.

Each stage of the plurality of bladed wheels **26** are coupled together to transmit torque from the turbine **18** to each of the plurality of bladed wheels **26**. The plurality of airfoils **30** extend into the gas path **15** of the compressor **14** and compress the air in the gas path **15**. The plurality of wheels **32** extend radially inward from the plurality of airfoils **30** and have an inner bore diameter **34**. The impeller **28** extends radially inward and has an impeller bore diameter **36**. The impeller bore diameter **36** is radially inward of the inner bore diameter **34** of the plurality of bladed wheels **26**. The plurality of bladed wheels **26** may be connected together to transfer torque through the rotor **20** via splines, fasteners, or other suitable alternatives. The tie bolt **22** transmits little to no torque during operation of the gas turbine engine **10**. The tie bolt **22** is configured to apply the compressive load AA to maintain engagement of the plurality of bladed wheels **26**.

The tie bolt **22** extends circumferentially around the central axis **11** and includes a forward flange **40**, an aft threaded portion **42**, a cylindrical segment **44**, and a spring segment **46** as shown in FIGS. **2** and **3**. The tie bolt **22** provides a compressive force to the rotor **20** throughout the engine cycle. The forward flange **40** extends axially forward and radially outward from the cylindrical segment **44**. The forward flange **40** has a radial dimension larger than the inner bore diameter **34** of the forward most plurality of wheels **32**. The forward flange **40** engages with the forward end of the rotor **20** to transmit the axial compressive force AA rearward on to the rotor **20**. The forward flange **40** may couple to forward end of the rotor **20** with a bolted joint, a curvic joint, a frictional surface joint, or a bonded joint. The aft threaded portion **42** is located at an aft terminal end of the tie bolt **22** and includes a threaded outer diameter that provides coupling means with the ring nut **24**. The aft threaded portion **42** extends axially aft of the impeller **28** and has an outer diameter less than the impeller bore diameter **36**.

In some embodiments, the compressor **14** may include a forward ring nut that couples with a forward threaded portion of the tie bolt **22**. The forward ring may have a larger outer diameter than the inner bore diameter **34** of the forward most plurality of wheels **32** so that it engages the forward end of the rotor **20** to transmit the compressive force AA rearward on the rotor **20**. In another embodiment, the tie bolt **22** may include a forward threaded portion that couples with a threaded inner diameter at a forward end of the rotor **20** and transmits the compressive force AA rearward on the rotor **20**.

The cylindrical segment **44** includes a first portion **50** and a second portion **52** in the illustrative embodiment as shown in FIGS. **2** and **3**. The first portion **50** has a constant outer diameter less than the inner bore diameter **34**, and extends axially aft from the forward flange **40**. The first portion **50** couples to the spring segment **46** at an aft terminal end of the first portion **50**. The second portion **52** has a constant outer diameter less than the inner bore diameter **34** and the impeller bore diameter **36**. The second portion **52** extends axially aft of the spring segment **46** and couples with the aft threaded portion **42**.

In some embodiments, the first portion **50** and the second portion **52** have the same outer diameter. In another embodiment, the first portion **50** may have a larger diameter than the second portion **52**. In a further embodiment, the first portion **50** may have a smaller outer diameter than the second portion **52**. In other embodiments, the cylindrical segment **44** extends only forward or aft of the spring segment **46**. In further embodiments, the first portion **50** and the second portion **52** may have varying diameters along the length of the first and second portions **50**, **52**. The first and second portions **50**, **52** may include step changes in the diameters along the lengths of the first and second portions **50**, **52** to accommodate engine geometry. The first and second portions **50**, **52** may also include changes in thickness along the lengths of the first and second portions **50**, **52**.

The spring segment **46** is located axially aft of the first portion **50** of the cylindrical segment **44** and axially forward of the second portion **52** of the cylindrical segment **44** as shown in FIG. **2**. The spring segment **46** includes a forward spring end **54**, and aft spring end **56**, and a bellows feature **58**. The forward spring end **54** is coupled to the aft end of the first portion **50** of the cylindrical segment **44**. The aft spring end **56** is coupled to the forward end of the second portion **52** of the cylindrical segment **44**. The bellows feature **58** extends axially aft of the forward spring end **54** and includes multiple diaphragms in series along the axial length in the illustrative embodiment. In other embodiments, the bellows feature **58** includes a single diaphragm.

Each diaphragm extends radially outward to a bellows outer diameter **60**, then axially aft a small length, and then radially inward. The bellows outer diameter **60** is less than the inner bore diameter **34** of the plurality of bladed wheels **26**. This allows the spring segment **46** of the tie bolt **22** to pass axially aft through the plurality of bladed wheels **26** of the rotor **20** when the compressor is assembled.

The stiffness of the spring segment **46** can be tuned for a compressor assembly to give a desired minimum compressive force AA that is to be maintained during engine running. The axial stiffness of the spring segment **46** can be adjusted by varying the number of diaphragms in the bellows feature **58**, the material of the bellows feature **58**, and the geometry of each diaphragm. The stiffness of the bellows feature **58** is less than the stiffness of the first and second portions **50**, **52** of the cylindrical segment **44**. The material of the spring segment **46** may be the same as the material of the cylindrical segment **44**. In other embodiments, the material of the spring segment **46** may be different from the material of the cylindrical segment **44**.

The axial location of the spring segment **46** along the tie bolt **22** can be varied depending on the geometry of the rotor **20**. In the illustrative embodiment shown in the FIG. **2**, the spring segment **46** is located axially forward of the impeller **28** and axially aft of the plurality of bladed wheels **26**. In some embodiments the spring segment can be located between individual wheels in the plurality of wheels **32**. The inner diameters of the rotor **20** and the outer diameter of the diaphragms may be varied depending on design criteria. Some or all of the plurality of bladed wheels **26** may have different inner diameters.

The spring segment **46** is integrated with the cylindrical segment **44** so that the tie bolt **22** is formed as a single-piece component as shown in FIG. **2**. In some embodiments, the spring segment **46** may be bonded to the cylindrical segment **44** by brazing, welding, or other suitable methods.

In the illustrative embodiment of FIG. **4**, the spring segment **46** is fastened to the cylindrical segment **44** using bolted flanges **70**. The bolted flanges **70** have outer diameters less than the inner bore diameter **34** of the plurality of bladed wheels **26** to enable assembly. In the illustrative embodiment of FIG. **4**, the bellows outer diameter **60** of the spring segment **46** may be larger than inner bore diameter **34** as the spring segment **46** may be assembled when the individual stages of the plurality of bladed wheels **26** are assembled together and does not need to axially pass through the rotor **20** for assembly.

In the illustrative embodiment of FIG. **5**, the spring segment **46** may be fastened to the cylindrical segment **44** using threaded portions **72**. In the illustrative embodiment of FIG. **5**, the bellows outer diameter **60** of the spring segment **46** may be larger than inner bore diameter **34** as the spring segment **46** may be assembled when the individual stages of the plurality of bladed wheels are assembled together and does not need to axially pass through the rotor **20** for assembly.

Another embodiment of a gas turbine engine **210** in accordance with the present disclosure is shown in FIGS. **6-8**. The gas turbine engine **210** is substantially similar to the gas turbine engine **10** shown in FIGS. **1-5** and described herein. Accordingly, similar reference numbers in the **200** series indicate features that are common between the gas turbine engine **210** and the gas turbine engine **10**. The description of the gas turbine engine **10** is incorporated by reference to apply to the gas turbine engine **210**, except in instances when it conflicts with the specific description and the drawings of the gas turbine engine **210**.

The gas turbine engine **210** includes a compressor rotor **220**, a turbine rotor **221**, a tie bolt **222**, and a ring nut **224** as shown in in FIGS. **6-8**. The tie bolt **222** is located radially inward of the compressor rotor **220** and the turbine rotor **221**. The tie bolt **222** extends axially through the compressor rotor **220**, the turbine rotor **221**, and past an aft end of the turbine rotor **221**. The ring nut **224** is assembled radially outward of the tie bolt **222** to an aft threaded portion **242** of the tie bolt **222**. The ring nut **224** has a threaded inner diameter that couples with to a threaded outer diameter of the aft threaded portion **242** of the tie bolt **222**. The ring nut **224** has an outer diameter larger than an inner diameter of the aft end of the turbine rotor **221** so that it engages the aft end of the turbine rotor **221** when the ring nut **224** is tightened in the forward direction.

The tie bolt **222** is stretched in the axial direction so that the tie bolt **222** maintains a compressive force in the assembly above the predetermined threshold throughout the engine cycle. Once a predetermined value of stretch of the tie bolt **222** has been achieved, the ring nut **224** is tightened against the aft end of the turbine rotor **221**. In some embodiments, the tie bolt **222** may be assembled axially forward through the rotors **220**, **221**, and the ring nut **224** may be located on a forward end of the tie bolt **222** and engage a forward end of the compressor rotor **220**.

The compressor rotor **220** includes a plurality of bladed wheels **226** that are assembled in series axially along the central axis **11** as shown in FIGS. **6** and **8**. In illustrative embodiment, the plurality of bladed wheels **226** includes an impeller **228** at the aft end of the compressor rotor **220**. The turbine rotor **221** includes a plurality of turbine wheel assemblies **227** that are assembled in series axially along the central axis **11**. The compressor rotor **220** rotates around the central axis **11** and is coupled to and driven by the turbine rotor **221**. In some embodiments, the compressor rotor **220** and the turbine rotor **221** may comprise a combination of bladed disk assemblies, impellers, and blisks.

The tie bolt **222** extends circumferentially around the central axis **11** and includes a forward flange **240**, an aft threaded portion **242**, a cylindrical segment **244**, and a spring segment **246** as shown in FIGS. **6-8**. The tie bolt **222** provides a compressive force to the compressor rotor **220** and the turbine rotor **221** throughout the engine cycle. This allows for the compressor rotor **220** to maintain connection with the turbine rotor **221** throughout the engine cycle. Torque is transmitted through the turbine rotor **221** and the compressor rotor **220**. The tie bolt **222** transmits little or no torque.

The forward flange **240** extends axially forward and radially outward from the cylindrical segment **244**. The forward flange **240** has a radial dimension larger than an inner bore diameter **234** of the forward most wheel in the compressor rotor **220**. The aft threaded portion **242** is located at an aft terminal end of the tie bolt **222** and extends axially aft of the turbine rotor **221**. The aft threaded portion **242** has an outer diameter less than a turbine inner bore diameter **235**.

In some embodiments, the compressor **214** may include a forward ring nut that couples with a forward threaded portion of the tie bolt **222**. The forward ring may have a larger outer diameter than the inner bore diameter **234** of the forward most plurality of bladed wheels **226** so that it engages the forward end of the compressor rotor **220** to transmit the compressive force AA rearward on the compressor rotor **220**. In another embodiment, the tie bolt **222** may include a forward threaded portion that couples with a threaded inner diameter at a forward end of the compressor rotor **220** and transmits the compressive force AA rearward on the compressor rotor **220**.

The cylindrical segment **244** includes a first portion **250** and a second portion **252** as shown in FIGS. **6-8**. In the illustrative embodiment, the first portion **250** has a constant outer diameter less than the inner bore diameter **234**, and extends axially aft from the forward flange **240**. The first portion **250** couples to the spring segment **246** at an aft terminal end of the first portion **250**. The second portion **252** has a constant outer diameter less than the inner bore diameter **234** and the turbine inner bore diameter **235**. The second portion **252** extends axially aft of the spring segment **246** and couples with the aft threaded portion **242**.

In some embodiments, the first portion **250** and the second portion **252** have the same outer diameter. In another embodiment, the first portion **250** may have a larger diameter than the second portion **252**. In a further embodiment, the first portion **250** may have a smaller outer diameter than the second portion **252**. In further embodiments, the first portion **250** and the second portion **252** may have varying diameters along the length of the first and second portions **250**, **252**. The first and second portions **250**, **252** may include step changes in the diameters along the lengths of the first and second portions **250**, **252** to accommodate engine geometry. The first and second portions **250**, **252** may also include changes in thickness along the lengths of the first and second portions **250**, **252**.

The spring segment **246** is located axially aft of the first portion **250** of the cylindrical segment **244** and axially forward of the second portion **252** of the cylindrical segment **244** as shown in FIGS. **6-8**. The spring segment **246** includes a forward spring end **254**, and aft spring end **256**, and a bellows feature **258**. The forward spring end **254** is coupled to the aft end of the first portion **250** of the cylindrical segment **244**. The aft spring end **256** is coupled to the forward end of the second portion **252** of the cylindrical segment **244**. The bellows feature **258** extends axially aft of the forward spring end **254** and includes multiple diaphragms in series along the axial length. Each diaphragm extends radially outward to a bellows outer diameter **260**, then axially aft a small length, and then radially inward.

The spring segment **246** is integrated with the first and second portions **250**, **252** of the cylindrical segment **244** as shown in FIGS. **6-8**. The spring segment **246** may be formed with the cylindrical segment **244** for form a single-piece tie bolt **222**. In some embodiments, the spring segment **246** may be fastened with the cylindrical segment **244** using bolted flanges. In another embodiment, the spring segment **246** may be coupled with the cylindrical segment **244** using threaded coupling means. In a further embodiment, the spring segment **246** may be bonded with the cylindrical segment **244** by brazing, welding, or other suitable methods.

In the illustrative embodiment of FIG. **6**, the bellows outer diameter **260** is less than the inner bore diameter **234** of the compressor rotor **220**. This allows the spring segment **246** of the tie bolt **222** to pass axially aft through the plurality of bladed wheels **226** of the compressor rotor **220** during assembly. The spring segment **246** is located axially forward of the impeller **228**. The bellows outer diameter **260** is greater than an inner impeller diameter **236** so the spring segment **246** is limited to being forward of the impeller **228** in this embodiment. The second portion **252** of the tie bolt **222** extends axially aft through the bore of the impeller **228** and the turbine inner bore diameter **235**.

In the illustrative embodiment of FIG. **8**, the spring segment **246** is located axially aft of the impeller **228**, and the tie bolt **222** is assembled from the aft end of the turbine rotor **221** axially forward through the assembly. The forward flange **240** is reversed in this configuration and engages the aft most turbine wheel assembly **227** of the turbine rotor **221**. The ring nut **224** assembles to a forward threaded portion of the tie bolt **222** and engages the forward most bladed wheel of the compressor rotor **220**. The bellows outer diameter **260** is less than the turbine inner bore diameter **235** of the turbine rotor **221**. This allows the spring segment **246** of the tie bolt **222** to pass axially forward through the plurality of turbine wheel assemblies **227** of the turbine rotor **221** during assembly. The bellows outer diameter **260** is greater than the inner impeller diameter **236** so the spring segment **246** is limited to being located aft of the impeller **228** in this embodiment. The first portion **250** of the tie bolt **222** extends axially forward through the bore of the impeller **228** and the compressor rotor **220**.

Another embodiment of a gas turbine engine **310** in accordance with the present disclosure is shown in FIG. **9**. The gas turbine engine **310** is substantially similar to the gas turbine engine **10** shown in FIGS. **1-5** and described herein. Accordingly, similar reference numbers in the **300** series indicate features that are common between the gas turbine engine **310** and the gas turbine engine **10**. The description of the gas turbine engine **10** is incorporated by reference to apply to the gas turbine engine **310**, except in instances when it conflicts with the specific description and the drawings of the gas turbine engine **310**.

The gas turbine engine **310** includes a turbine rotor **321**, a tie bolt **322**, and a ring nut **324** as shown in in FIG. **9**. The tie bolt **322** is located radially inward of the turbine rotor **321**. The tie bolt **322** extends axially through the turbine rotor **321** and past an aft end of the turbine rotor **321**. The ring nut **324** is assembled radially outward of the tie bolt **322** to an aft threaded portion **342** of the tie bolt **322**. The ring nut **324** has a threaded inner diameter that couples with to a threaded outer diameter of the aft threaded portion **342** of the tie bolt **322**. The ring nut **324** has an outer diameter larger than an inner diameter of the aft end of the turbine rotor **321** so that it engages the aft end of the turbine rotor **321** when the ring nut **324** is tightened in the forward direction.

The turbine rotor **321** includes a plurality of turbine wheel assemblies **327** that are assembled in series axially along the central axis **11** as shown in FIG. **9**. The turbine rotor **321** rotates around the central axis **11** and drives the compressor **314** and fan **312**. The tie bolt **322** is stretched in the axial direction so that the tie bolt **322** can maintain a compressive force on a plurality of turbine wheel assemblies **327** above a predetermined threshold throughout the engine cycle. Once a predetermined value of stretch of the tie bolt **322** has been achieved, the ring nut **324** is tightened against the aft end of the turbine rotor **321**.

The tie bolt **322** extends circumferentially around the central axis **11** and includes a forward flange **340**, an aft threaded portion **342**, a cylindrical segment **344**, and a spring segment **346** as shown in FIG. **9**. The tie bolt **322** provides the compressive force to the turbine rotor **321** above the predetermined threshold throughout the engine cycle. This allows for the plurality of turbine wheel assemblies **327** to maintain connection with one another throughout the engine cycle. The forward flange **340** extends axially forward and radially outward from the cylindrical segment **344**. The forward flange **340** has a radial dimension larger than a turbine inner bore diameter **335** of the forward most wheel in the plurality of turbine wheel assemblies **327**. The aft threaded portion **342** is located at an aft terminal end of the tie bolt **322** and extends axially aft of the turbine rotor **321**. The aft threaded portion **342** has an outer diameter less than a turbine inner bore diameter **335**.

In some embodiments, the turbine **318** may include a forward ring nut that couples with a forward threaded portion of the tie bolt **322**. The forward ring may have a larger outer diameter than the turbine inner bore diameter **335** of the forward wheel in the plurality of turbine wheel assemblies **327** so that it engages the forward end of the turbine rotor **321** to transmit the compressive force AA rearward on the turbine rotor **321**. In another embodiment, the tie bolt **322** may include a forward threaded portion that couples with a threaded inner diameter at a forward end of the turbine rotor **321** and transmits the compressive force AA rearward on the rotor **321**.

The cylindrical segment **344** includes a first portion **350** and a second portion **352** as shown in FIG. **9**. In the illustrative embodiment, the first portion **350** has a constant outer diameter and extends axially aft from the forward flange **340**. The first portion **350** couples to the spring segment **346** at an aft terminal end of the first portion **350**. The second portion **352** has a constant outer diameter less than the turbine inner bore diameter **235**. The second portion **352** extends axially aft of the spring segment **346** and couples with the aft threaded portion **342**.

In some embodiments, the first portion **350** and the second portion **352** have the same outer diameter. In another embodiment, the first portion **350** may have a larger diameter than the second portion **352**. In a further embodiment, the first portion **350** may have a smaller outer diameter than the second portion **352**. In further embodiments, the first portion **350** and the second portion **352** may have varying diameters along the length of the first and second portions **350**, **352**. The first and second portions **350**, **352** may include step changes in the diameters along the lengths of the first and second portions **350**, **352** to accommodate engine geometry. The first and second portions **350**, **352** may also include changes in thickness along the lengths of the first and second portions **350**, **352**.

The spring segment **346** is located axially aft of the first portion **350** of the cylindrical segment **344** and axially forward of the second portion **352** of the cylindrical segment **344** as shown in FIG. **9**. The spring segment **346** includes a forward spring end **354**, and aft spring end **356**, and a bellows feature **358**. The forward spring end **354** is coupled to the aft end of the first portion **350** of the cylindrical segment **344**. The aft spring end **356** is coupled to the forward end of the second portion **352** of the cylindrical segment **344**. The bellows feature **358** extends axially aft of the forward spring end **354** and includes multiple diaphragms in series along the axial length. Each diaphragm extends radially outward to a bellows outer diameter **360**, then axially aft a small length, and then radially inward.

The spring segment **346** is integrated with the first and second portions **350**, **352** of the cylindrical segment **344** as shown in FIG. **9**. The spring segment **346** may be formed with the cylindrical segment **344** for form a single-piece tie bolt **322**. In some embodiments, the spring segment **346** may be fastened with the cylindrical segment **344** using bolted flanges. In another embodiment, the spring segment **346** may be coupled with the cylindrical segment **344** using threaded coupling means. In a further embodiment, the spring segment **346** may be bonded with the cylindrical segment **344** by brazing, welding, or other suitable methods.

In a gas turbine engine **10**, a plurality of bladed wheels **26** may be clamped together in some fashion in order to transfer torque developed from the flow path **15**. During assembly of a tie-bolt **22** as shown in FIG. **2**, the rotor **20** may be stacked on the tie bolt **22**. Tooling may be used to stretch the tie bolt **22** and a spanner nut **24** may be subsequently torqued down to react the load imparted from the stretch through the rotor **20**.

Since a conventional tie-bolt is typically cylindrical, it is relatively stiff and generates large loads over a small stretch range. Due to differences in materials and masses in a tie-bolted rotor configuration, thermal growth of the conventional tie bolt is often very different from the rest of the rotor components which results in large reductions in clamp load during mission transients. Under some conditions, the rotor may shrink faster than the tie bolt, effectively reducing the stretch used to generate the clamp force holding the rotor together. To ensure the rotor maintains positive clamp throughout its duty cycle, large pre-loads, by stretching the tie bolt, are used with conventional tie bolts at assembly which can be difficult to execute efficiently in a shop environment. When a tie bolt is used to clamp both a compressor and turbine rotor, the thermal mismatch between the tie bolt may be further exacerbated by the relatively cool compressor and relatively hot turbine.

The presented disclosure provides solutions to the above mentioned challenges. The present disclosure provides for a spring segment **46** in the tie bolt **22** to allow larger assembly stretch while keeping assembly loads manageable. The spring segment **46** may reduce the stiffness of the tie-bolt **22**, allowing more assembly pre-stretch to be obtained at a given assembly load. Thus, a larger operational deflection range can be accommodated for a given assembly stretch. This is accomplished either through a feature integral to the tie-bolt as shown in FIGS. **2** and **3**, a separate component bolted into the tie-bolt as shown in FIG. **4**, or a separate component threaded onto the shaft in a turnbuckle-style configuration as shown in FIG. **5**.

While the disclosure has been illustrated and described in detail in the foregoing drawings and description, the same is to be considered as exemplary and not restrictive in character, it being understood that only illustrative embodiments thereof have been shown and described and that all changes and modifications that come within the spirit of the disclosure are desired to be protected.

What is claimed is:

1. A gas turbine engine assembly comprising

a rotor that includes a plurality of bladed wheels configured to rotate about an axis and interact with gases located radially outward of the rotor,

a tie bolt that extends axially through the rotor along the axis and applies an axial compressive force to the plurality of bladed wheels to maintain axial connection between the plurality of bladed wheels, the tie bolt including a cylindrical segment and a spring segment coupled with the cylindrical segment and having a varying outer diameter to form a bellows feature,

wherein the cylindrical segment has a first stiffness and the spring segment has a second stiffness that is less than the first stiffness to allow the tie bolt to expand and contract with the rotor due to thermal growth caused during use of the gas turbine engine assembly while maintaining the axial compressive force applied to the plurality of bladed wheels above a predetermined value,

wherein the tie bolt includes a flange and a nut spaced apart axially from the flange, the flange and the nut are coupled with the cylindrical segment and cooperate to apply the axial compressive force to the plurality of bladed wheels, and the spring segment is located axially between the flange and the nut to accommodate for thermal growth of the tie bolt while maintaining the axial compressive force applied to the plurality of bladed wheels above the predetermined value during use of the gas turbine engine assembly.

2. The gas turbine engine assembly of claim **1**, wherein the spring segment is fastened with the cylindrical segment for rotation therewith.

3. The gas turbine engine assembly of claim **1**, wherein the spring segment is threaded to the cylindrical segment for rotation therewith.

4. The gas turbine engine assembly of claim **1**, wherein the spring segment is integrally formed with the cylindrical segment.

5. The gas turbine engine assembly of claim 1, wherein the spring segment is one of brazed and welded to the cylindrical segment for rotation therewith.

6. The gas turbine engine assembly of claim 1, wherein the cylindrical segment is made of first materials and the spring segment is made of second materials different from the first materials.

7. The gas turbine engine assembly of claim 1, wherein the plurality of bladed wheels includes compressor wheels.

8. The gas turbine engine assembly of claim 7, wherein the plurality of bladed wheels further includes turbine wheels.

9. The gas turbine engine assembly of claim 1, wherein the cylindrical segment includes a first portion having a constant outer diameter and a second portion having a constant outer diameter and the spring segment is located between and coupled to the first portion and the second portion of the cylindrical segment.

10. The gas turbine engine assembly of claim 9, wherein the varying outer diameter of the spring segment has a maximum diameter and at least one of the plurality of bladed wheels has an inner diameter that is greater than the maximum diameter.

11. A gas turbine engine assembly comprising

a rotor that includes a plurality of wheels configured to rotate about an axis,

a tie bolt that extends axially through the rotor along the axis and applies an axial compressive force to the plurality of wheels, the tie bolt including a first segment having a first stiffness and a second segment formed to define a bellows feature and having a second stiffness that is less than the first stiffness,

wherein the first segment includes a first portion having a first outer diameter and a second portion having a second outer diameter, and the second segment has a third outer diameter that is greater than the first outer diameter and the second outer diameter,

wherein the tie bolt includes a first engagement feature coupled with the first portion of the first segment of the tie bolt and a second engagement feature spaced apart axially from the first engagement feature and coupled with the second portion of the first segment of the tie bolt, the first engagement feature and the second engagement feature cooperate to apply the axial compressive force to the plurality of wheels between the first engagement feature and the second engagement feature, and the second segment having the second stiffness is located axially between and coupled to the first portion and the second portion of the first segment.

12. The gas turbine engine assembly of claim 11, wherein the first segment is coupled with the second segment and the second segment has a varying outer diameter to form the bellows feature.

13. The gas turbine engine assembly of claim 11, wherein the second segment has a maximum diameter and at least one of the plurality of wheels has an innermost diameter that is greater than the maximum diameter.

14. The gas turbine engine assembly of claim 11, wherein the plurality of wheels includes an impeller.

15. The gas turbine engine assembly of claim 11, wherein the plurality of wheels includes bladed turbine wheels.

16. The gas turbine engine assembly of claim 11, wherein the first segment and the second segment of the tie bolt are separate components that are coupled together for common rotation about the axis.

17. A method comprising

arranging a plurality of bladed wheels around a tie bolt that extends along an axis, the tie bolt including a cylindrical segment having a first stiffness and a spring segment formed to define a bellows feature and having a second stiffness that is less than the first stiffness, the tie bolt further including a flange and a nut spaced apart axially from the flange, the flange and the nut being coupled with the cylindrical segment, and the spring segment is located axially between the flange and the nut, wherein a gas turbine engine assembly comprises a rotor that includes the plurality of bladed wheels, the plurality of bladed wheels configured to rotate about the axis and interact with gases located radially outward of the rotor, and the spring segment is coupled with the cylindrical segment and having a varying outer diameter to form the bellows features, and

compressing axially the plurality of bladed wheels with the flange and the nut of the tie bolt to cause the spring segment to deform elastically and accommodate for thermal growth of the tie bolt while maintaining an axial compressive force applied to the plurality of bladed wheels above a predetermined value during use of the gas turbine engine assembly, wherein the second stiffness allows the tie bolt to expand and contract with the rotor due to thermal growth caused during use of the gas turbine engine assembly while maintaining the axial compressive force applied to the plurality of bladed wheels above the predetermined value.

18. The method of claim 17, further comprising coupling the cylindrical segment with the spring segment for rotation therewith about the axis.

19. The method of claim 17, wherein the plurality of bladed wheels includes a first bladed wheel having a first innermost diameter and a second bladed wheel having a second innermost diameter, the bellows feature having a maximum outer diameter, and the maximum outer diameter is less than the first innermost diameter and greater than the second innermost diameter.

20. The gas turbine engine assembly of claim 11, wherein the first engagement feature is a flange coupled with the first portion of the first segment of the tie bolt and the second engagement feature is a nut coupled with the second portion of the first segment of the tie bolt.

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